Probing the time-course of facilitation and inhibition in gaze cueing of attention in an upper-limb reaching task

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This paper has been accepted for publication in Attention, Perception and Psychophysics and can be accessed through this link: https://doi.org/10.3758/s13414-019-01821-5

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Abstract

Previous work has revealed that social cues, such as gaze and pointed fingers, can lead to a shift in the focus of another person's attention. Research investigating the mechanisms of these shifts of attention has typically employed detection or localization button pressing tasks. Because in-depth analyses of the spatio-temporal characteristics of aiming movements can provide additional insights into the dynamics of the processing of stimuli, the current study used a reaching paradigm to further explore the processing of social cues. In Experiments 1 and 2, participants aimed to a left or right location after a non-predictive eye gaze cue towards one of the target locations. Seven stimulus onset asynchronies (SOAs) between 100 and 2400 ms were used. Both temporal (reaction time-RT) and spatial (initial movement angle-IMA) characteristics of the movements were analysed. RTs were shorter for cued (gazed-at) targets than to uncued targets across most SOAs. There were, however, no statistical differences in IMA between movements to cued and uncued targets suggesting action planning was not affected by the gaze cue. In Experiment 3, the social cue was a finger pointing to one of the two target locations. Finger pointing cues generated significant cuing effects in both RT and IMA. Overall, these results indicate that eye gaze and finger pointing social cues are processed differently. Perception-action coupling (i.e., a tight link between the response and the social cue that is presented) may play a role in the generation of action, and deviation of trajectories towards cued and uncued targets.

Max Words: 250

Word Count: 249

Introduction

During social interactions, individuals process the movements of other people for a variety of purposes such as engaging in non-verbal communication, decoding intention, and coordinating action. One important cue used during social interactions is the direction of eye gaze. Indeed, gaze has been repeatedly shown to be a powerful biological orienting cue (e.g., Friesen & Kingstone, 1998; see Frischen, Bayliss, & Tipper, 2007 for review). Other cues, such as a pointed finger, might act similarly (e.g., Ariga & Watanabe, 2009). Even though different social cues are used for similar purposes, they are likely to be processed differently. Separate regions of the extra-striate and other visual cortices process body and face stimuli (see Peelen & Downing, 2007 for review), and there are separate networks of motor areas that process information for the generation of hand and eye movements (Cisek & Kalaska, 2010; Kandel, Schwartz, & Jessell, 2000). As such, pointing and gaze cues might also be decoded using separate networks. The present paper reports a set of studies designed to further understanding of the mechanisms involved in the processing of social gaze and pointing cues by using an upper limb-reaching task. The spatial and temporal characteristics of reaching movements to target locations were used here because such analyses can provide additional information concerning the dynamics of the cognitive mechanisms involved in the cuing paradigm (see Song & Nakayama, 2009; Welsh & Weeks, 2010).

The Time-Course of Cuing Effects

The present studies involved an adapted version of the conventional spatial cueing paradigm (Posner, 1980; Posner & Cohen, 1984). In a common version of this paradigm, a sudden onset cue is presented peripherally at one of two potential target locations. Even though the cue is non-predictive of the target location, RTs are affected by the cue, with the direction of

this influence being dependent on the timing of the cue and target onsets (the stimulus onset asynchrony; SOA). A facilitation effect of the cue (shorter RTs for targets at cued over uncued locations) emerges at short (~ 100 ms) SOAs. This facilitation is thought to emerge because the cue has rapidly drawn attention to its location. At SOAs longer than 300 ms, however, RTs are actually longer to cued targets than to uncued targets (Posner & Cohen, 1984). This latter pattern of longer RTs to cued than uncued targets is termed inhibition of return (IOR). It is thought that, as a consequence of attention being redirected from the cued location back to the central fixation point, a residual inhibitory code is placed on the location of the cue and/or on the response to the cued location (Posner & Cohen, 1984; see Klein, 2000 for review). This inhibitory code hinders the reorientation of attention back to the cued location and/or the processing of the sensory information at the previously cued/attended location.

When the spatial cue is presented centrally, however, the time-course and pattern of cuing effects is distinct from that which emerges when peripheral cues are used. While peripheral cues typically illicit facilitation that peaks at very short SOAs (100ms), maximal facilitation effects following central cues typically take longer to arise, occurring typically around 300 ms. Further, IOR is typically not observed (Cheal & Lyon, 1991; Muller & Rabbitt, 1989). Consequently, peripheral and central cueing paradigms differ in the nature of their behavioural effects on attention orienting and, because of these differences, they are often thought to have separate loci of control. Therefore, it may be possible to distinguish the mechanisms involved in processing the various cues based on the pattern of RTs to cued and uncued targets that emerge following different types of cues (e.g., peripheral vs. central). Indeed, the examination of the time-course of the cuing effects following the presentation of a central face with gaze directed towards one of two placeholders has been central to longstanding debate

on whether or not gaze cues share the mechanisms involved in peripheral or central gaze cuing (or an entirely different mechanism) (see Frischen, Bayliss, et al., 2007 for review).

The Processing of Gaze and Finger-Point Cues

The research on social gaze cues has revealed that these cues seem to share properties of both peripheral and central cues. Because gaze cues are presented at central fixation and do not involve a dynamic change in the periphery at a potential target location, gaze cues most resemble central cues. However, the processing advantages (as seen in RTs) from gaze cues can resemble peripheral cues in that they tend to show facilitation effects at very short SOAs (100-300 ms) and these early facilitation effects are relatively immune to top-down influences such as the instruction to ignore the gaze cue (e.g. Driver et al., 1999; Friesen & Kingstone, 1998, see Frischen et al., 2007 for review). In contrast to the effects of peripheral cues (e.g., Posner & Cohen, 1984), however, the facilitation effects stemming from gaze cues are still present at longer SOAs (700-1000 ms) though the facilitation effects do gradually diminish (Frischen, Bayliss, et al., 2007). Additionally, IOR is rarely observed in RTs following gaze cues, with the exception of at SOAs greater than 2000 ms and only when there is an event to disengage attention from the gazed-at location and draw it back to central fixation, such as a mask or an offset of the gaze cue (Frischen, Smilek, Eastwood, & Tipper, 2007; Frischen & Tipper, 2004). In sum, it is not clear from the data if the mechanisms involved in gaze cueing of attention are most similar to those used in peripheral cueing, central cueing, or something different altogether.

The processing of finger pointing cues has received comparatively little study. In one of the few studies to examine the time-course of cuing effects following pointing cues, Ariga and Watanabe (2009) found that there was a facilitation effect at the pointed-to location at a short (107ms) SOA, but no difference between RTs to targets at the pointed-to and non-pointed-to

location at a longer (1000ms) SOA. The pattern of cuing effects (short-term facilitation with no IOR) is similar to that observed following gaze cues. Interestingly, IOR-like effects have been observed when participants were required to reach and touch a target location more than 1200 ms after a co-actor pointed to one of two targets (Experiment 3, Atkinson, Simpson, Skarratt, & Cole, 2014). Specifically, RTs were longer for targets presented at locations that the co-actor had previously pointed towards than for targets at the other location. These data suggest that the mechanisms of IOR may be activated following a finger pointing stimulus. Overall, relatively little research has been conducted on understanding the processing of finger cues, but these few studies do suggest that these stimuli can generate shifts of attention.

An Action-Centred Approach

The extant work in this area of social cuing has typically used discrete button pressing tasks to record RT and assess orienting of attention. However, it is of interest to investigate social cues from an action-oriented approach because human behaviour requires interaction with objects in the environment via reaching, grasping, and manipulation actions. Further, the recording and analysis of reaching movements provides additional variables and measures which may generate deeper insights into cognitive processes. Deviations in an individual's upper limb trajectory towards or away from non-target stimuli while reaching towards a target may give an index of the locus of attention and the dynamics of the continuous processing of information (Gallivan & Chapman, 2014; Song & Nakayama, 2009); and in particular the coupling between action and attention (see Welsh & Weeks, 2010, for review). Thus, it has become evident that investigating changes in the spatial and temporal characteristics of motor responses may provide new and nuanced insight into the dynamics of the cognitive mechanisms that enable complex behaviour. Further, examining the trajectories of reaching movements can provide information

on ongoing cognitive mechanisms (see also Chapman et al., 2010; Gallivan & Chapman, 2014; Moher & Song, 2013; Welsh & Elliott, 2004).

Though attention and action may be tightly coupled (see Welsh, 2011), there may be differences in how the relevant orienting and prioritization mechanisms temporally propagate throughout attentional and motor networks. In work concerning the processing of non-predictive peripheral cues, Neyedli and Welsh (2012) mapped the time-course of facilitation and inhibition following the onset of an attention-capturing peripheral cue in a reaching task. Participants executed aiming movements to targets presented at one of three potential locations 100, 350, 850, or 1100 ms after the onset of a non-predictive peripheral cue (a 50 ms "flash") at one of the potential target locations. The time-course of RTs to cued and uncued targets was similar to the previously described time-course in traditional peripheral cuing tasks wherein IOR emerges; participants had significantly shorter RTs to uncued targets than to cued targets at SOAs of 350 ms, 850 ms and 1100 ms. No facilitation effect at 100 ms, however, was observed for RTs. The pattern of trajectory deviations differed slightly from this RT pattern. Specifically, even though no facilitation was observed and an inhibitory influence on RT was observed at 350 ms and later, movement trajectories deviated towards cued locations at SOAs lower than 350 ms (revealing a facilitation effect associated with the response to the cue) and then deviated away from cued locations at the larger SOAs of 850 and 1000 ms (revealing an inhibition effect associated with the response to the cue). These data indicate that the mechanisms that generate "attentional" facilitation and inhibition are represented in the motor system and influence the execution of action, but that motoric facilitation (presence of a competing response) lasted longer and motoric inhibition (inhibition of that competing response) was relatively delayed when compared to manifestation of facilitation and inhibition in RTs. This pattern of RTs and trajectory effects was

replicated in a further study with smaller increments between SOAs (Welsh, Neyedli, & Tremblay, 2013). Consequently, it is possible that different behavioural expressions of facilitation and inhibition are seen in RTs and in measures of trajectory deviation. As such, kinematic analyses of reaching movements can provide new insights into the sensorimotor systems involved in the processing of different types of stimuli. For this reason, investigating attention orienting cues with upper-limb reaching movements can clearly provide additional insight into the associated neural mechanisms.

The Present Experiments

The purpose of the current experiments was to examine the mechanisms underlying the processing of social cues (gaze and pointing) by examining the influences of these cues on the spatial and temporal characteristics of upper-limb reaching movements. Three experiments are reported herein. Experiments 1 and 2 concern gaze cues and Experiment 3 concerns finger pointing cues. We predict several patterns of data based on the premise that social cues engage attentional mechanisms and these attentional mechanisms are linked to and exert an influence on the motor system (as in Welsh, 2011, for example). If social cues engage mechanisms that are similar to those engaged with the bottom-up processing of peripheral cues, then patterns of RTs and movement trajectory deviations, and dissociations between the two behavioural effects, similar to those observed in Neyedli and Welsh (2012) may be observed here. Specifically, it was predicted that RTs may be shorter to cued than to uncued targets at short SOAs, and trajectories to uncued targets will deviate towards the cued location at short SOAs. Predictions regarding deviations towards or away from the cued location at longer SOAs were unclear given the previously observed differences in the emergence of the spatial and temporal effect at longer SOAs (Neyedli & Welsh, 2012). Indeed, it even was possible that inhibitory mechanisms may

work in the motor system while excitatory mechanisms operate in attention. On the other hand, if attentional shifts following social cues do not drive response producing processes to interact with the object at the cued location, then even though there still may be cuing effects in RTs, the trajectories of movements to uncued and cued target locations will not differ.

Experiment 1

Participants in Experiment 1 completed aiming movements to targets that appeared randomly at a left or right target location. A gaze cue preceded the onset of the target by SOAs varying between 100 and 2400 ms. Based on previous research, it was predicted that RTs would be shorter to cued targets than uncued targets at most SOAs. It is possible, though unlikely, that RTs to cued targets may be longer than to uncued targets at the longest SOA because the gaze cue in this experiment remained fixed on the potential target location throughout a given trial (see Frischen & Tipper, 2004). The pattern of trajectory deviations of the hand movements to the target will depend on the relationship between attention and action systems and the mechanisms that generate the changes in RTs following gaze cues. Although it is unlikely for IOR to emerge in RTs, it is possible that such effects of inhibition may be detected in the trajectory deviations as a dissociation between these behavioural effects has previously been shown (e.g. Neyedli & Welsh, 2012; Welsh et al., 2013).

Methods

Participants. Twenty participants (15 women, 5 men) aged nineteen to thirty-seven years (mean age = 26 years) were recruited from the University of Toronto community. All participants were right-hand dominant and had normal or corrected to normal vision. Participants provided full and informed consent and they were monetarily compensated for their time. All

procedures were approved and were consistent with the standards put forth by the University of Toronto Research Ethics Board.

Apparatus. Participants sat comfortably in front of a 24-inch widescreen monitor (Acer GD235HZ) with a resolution of 1920 (w) by 1080 (h) pixels. The monitor was angled approximately 20 degrees from the surface of the table. The initial display included a home position (a blue circle 1.5 cm in diameter) located 1 cm above the bottom of the screen, and two open blue square target placeholders (2 cm) that were located approximately 28 cm horizontally from one another and 25 cm diagonally from the home position. The cue stimulus was the image of a young adult male face, whose gaze (face and eyes) was initially directed centrally towards the participant. The face measured approximately 6 cm (w) and 8 cm (h) and was centred between the two target placeholders. The eye-gaze cue consisted of an image of the same male with the iris and pupils displaced to the left or right. All images were presented on a light grey background. Throughout the experiment, participants were in view of an optoelectric motion tracking system (Optotrack, Northern Digital Inc., Waterloo, Ontario, Canada). An infrared emitting diode (IRED) was attached to the participants' right index fingers and the motion of this IRED was recorded at a rate of 250 Hz for 1500 ms, starting at the onset of the target.

Task and procedure. In a given trial, a participant would begin with his or her right index finger on the home position. After 1000 ms the eyes of the face presented in the visual display would shift towards the left or right target placeholder, providing a non-predictive gaze cue (see Figure 1 for a schematic depiction of the time-course of a given trial). After a variable SOA (100, 250, 400, 700, 1000, 1700, and 2400 ms), one of the target placeholders would become solid, signalling the participant to move their index finger from the home position to the given target placeholder as soon as possible. We used a relatively long range of SOAs to assess

the time-course of facilitation and potential inhibition (as it was at these longer SOAs that IOR for gaze cues was observed by Frischen & Tipper, 2004).

The participant's movements were recorded for 1500 ms after which the display would reset to the initial display and the participant could initiate another trial by placing his or her finger in the home position. Participants were instructed to move towards and touch the target location as soon as they saw one of the target placeholders become solid. They were informed that the preceding gaze cue was entirely non-predictive (i.e., that the target would appear on both the left and right side equally and randomly, and the cue and SOA were presented randomly with respect to the target). The target could be presented either at the cued (i.e., in the location specified by the cue) or uncued (i.e., in the direction opposite the cue) location. Fifteen cued and uncued trials were performed for both the left and right target placeholder at each of the seven SOAs for a total 420 experimental trials. Trial types were randomly distributed throughout the experiment and were broken up into five blocks of eighty-four trials with self-paced breaks in between each block. Prior to the experimental trials, participants executed fourteen practice trials. The total time in testing was approximately 1 hour.

Data reduction and analysis. The data were stored for offline analysis using a custom analysis program to calculate kinematic data using Matlab (The Mathworks Inc.). IRED position data were filtered using a second order dual pass Butterworth filter with a low-pass cut-off frequency of 10Hz. The position data were then differentiated to obtain instantaneous velocity of the movement. The start and the end of the movement were identified as the first sample in which instantaneous velocity in the z-axis (vertical axis) surpassed and fell below 50mm/s for three consecutive samples, respectively. Each trial was visually inspected. If this criteria did not isolate the start and end of the movement properly (for example, due to the participant making

unnecessary movement at the home or end position), the start and end of movement was determined visually. Reaction time (RT) was defined as the time from target onset to the calculated movement start. Movement time (MT) was defined as the time from the calculated movement start to the calculated movement end.

Calculation of initial movement angle. Initial movement angle for a given trial was calculated to provide an index of the initial curvature or direction of a participant's movement. This measure was calculated by finding the absolute angle in degrees between the y axis, and the line created from the (x,y) coordinates of their starting position and the (x,y) coordinates of the participant's position at 20% of their movement trajectory. This measure was chosen because it represented a point in the movement trajectory that best represented the initial representations of action in the motor system because it was early enough such that the trajectory was not likely subject to online corrective processes based on visual information (Elliott et al., 2010; see Footnote 1).

Outlier analysis. Thirty-five trials across all participants (0.4% of all data) were removed prior to analysis for obvious recording and/or experimental error. Trials in which a participant's RT was less than 100 ms or greater than 1000 ms as well as trials in which MT was greater than 1000ms were removed from the analysis (0.1% of all data). Following these initial screenings, trials in which RT fell outside of 2.5 standard deviations for each participant and condition were removed from the analysis (2% of all data). Overall, 2.6% of the entire data set was excluded from analysis.

Statistical analysis. A 2 (Target: cued, uncued) X 7 (SOA: 100, 250, 400, 700, 1000, 1700, 2400 ms) repeated measures ANOVA was conducted on each of the three dependent measures: RT, MT and IMA. For each of these analyses, where Mauchly's test of sphericity

indicated that the assumption of sphericity was violated, Hyun-Feldt corrected values are reported (indicated by degrees of freedom with decimals). Where a significant interaction was found, planned comparisons were conducted to determine differences between cued and uncued trials at each of the seven SOAs.

Results

Reaction time. Significant main effects for Target, $F(1,19) = 42.97$, $p < .001$, $\eta_p^2 = .69$ and SOA, $F(3.19, 60.63) = 10.32$, $p < .001$, $\eta_p^2 = .35$ were found (Figure 4, top left). The main effect for Target revealed that RTs on cued target trials ($M = 299$ ms, $SD = 46.98$) were shorter than those on uncued target trials ($M = 310$ ms, $SD = 48.46$). For the main effect of SOA, examination of the RT data presented in Figure 4 suggest that RTs were longer at shorter SOAs and generally decreased as SOA increased – consistent with this observation, there was a significant linear trend, $F(1,19) = 17.07$, $p < .01$, $\eta_p^2 = .47$. There was no significant Target by SOA interaction, $F(6,114) = 1.78$, $p = .11$, $\eta_p^2 = .09$. This result indicates that there were no statistical differences in the cuing effect that emerged across the seven SOAs, and in particular no evidence of IOR at the long SOAs.

Movement time. There were no significant main effects of Target, $F(1,19) = 1.42$, $p = .25$, $\eta_p^2 = .07$, or SOA, $F(4.75, 90.26) = 1.02$, $p = .41$, $\eta_p^2 = .05$, and no significant interaction between Target and SOA, $F(6,114) = 1.35$, $p = .24$, $\eta_p^2 = .07$. Consequently, it is clear that neither the cue nor SOA had any significant effect on MT.

Initial movement angle. There were no significant main effects of Target, $F(1,19) = .001$, $p = .98$, $\eta_p^2 < .001$, or SOA, $F(4.46, 5.90) = 2.26$, $p = .06$, $\eta_p^2 = .10$, and no significant interactions between the two factors, $F(4.55, 86.35) = 1.81$, $p = .12$, $\eta_p^2 = .09$ (Figure 4, top right). Therefore, neither cue nor SOA had a significant effect on IMA in this experiment.

Discussion

The current experiment used an upper-limb aiming task to investigate the motoric and attentional components of facilitation and inhibition in a gaze-cueing task. Participants reached towards a left or right target placeholder in the presence of a gaze cue that was either in the direction of, or opposite to, the target. Two key findings were revealed.

First, RTs to cued targets were shorter than RTs to uncued targets. This facilitation effect associated with the centrally-presented social cue is consistent with the results of previous literature (Friesen & Kingstone, 1998; Frischen, Smilek, et al., 2007; Frischen & Tipper, 2004). However, the absence of interaction between RT and SOA suggests that there were no statistically significant changes in the cuing effect as the time between the cue and the target increased. Thus, the eye gaze cue and reaching task used in this experiment did not lead to the patterns of RTs to cued and uncued targets in previous gaze cueing experiments (i.e., short-term facilitation and later diminishing of cueing effects and possibly IOR; see also Frischen et al., 2007; Frischen & Tipper, 2004).

The second and perhaps more novel finding was that the social gaze cue did not affect the temporal (MT) nor the spatial (IMA) characteristics of movement. This latter finding of an absent cuing effect in IMA was not expected given the history of previous work demonstrating coupling between attentional effects observed in RTs and IMAs (e.g., Lee, 1999; Neyedli & Welsh, 2012; Welsh, 2011; Welsh et al., 2013). This unexpected distinction may suggest that, although gaze cues are capable of influencing information processing and response initiation processes, these processes may be less tightly coupled with the manual motor system.

Experiment 2

Experiment 2 was designed and conducted to further address the processing of gaze cues because the results of Experiment 1 were not entirely consistent with the findings of previous work on cuing effects in two main ways. First and foremost, although facilitatory cuing effects were present in RTs, there were no differences in the trajectories of the executed aiming movements. This distinction between the presence of cuing effects in RTs and the absence of cuing effects in trajectories is not consistent with a series of studies revealing cuing effects in both RTs and trajectories when peripheral cues are used (e.g., Lee, 1999; Neyedli & Welsh, 2012; Welsh, 2011; Welsh et al., 2013). Thus, the data from Experiment 1 suggest that gaze cues may not activate responses in the same way as peripheral cues. Given this unexpected result, Experiment 2 was conducted to provide an additional testing of the prediction that response codes will be activated following the shift of attention generated by gaze cues.

Second, the gaze cues in Experiment 1 led to a somewhat different pattern of RTs from those revealed in previous studies of gaze cues. Specifically, there was an overall facilitation effect associated with the cue in RTs, and this effect was not significantly different across SOAs. This latter RT effect is not entirely consistent with, for example, the results of the study by Frischen and Tipper (2004) who demonstrated that no cueing effects were present at the 1200 ms SOA. It is possible that the chosen methodology may account for the discrepancy in results. In Experiment 1 reported herein, the central face remained gazing towards the placeholder throughout the longest SOA period. In the Frischen and Tipper (2004) study, the greatest changes across SOA were found when the methodology increased the potential that attention would be removed from the cued peripheral target. For instance, IOR emerged at the long SOA when the central face with the gaze cue was masked with a fixation cross before the presentation of the target because it is likely that the mask and disappearance of the gaze cue disengages

attention from the cued location (and presumably reengages attention centrally). Thus, it is likely that sustained cuing effects in Experiment 1 were due to the continued orientation of the central gaze cue to one of the target locations. It is possible that the chosen methodology also failed to engage the response-producing processes in the motor system which in turn led to the non-effects of cue on movement trajectories (see previous paragraph). Therefore, the gaze of the face in Experiment 2 returned to a neutral position (i.e., direct gaze at the participant) 150 ms after the initial presentation of the gaze cue towards one of the cued locations. This return of gaze to the central location may have the effect of disengaging attention from the peripheral location and drawing it back to central fixation (Böckler, van der Wel, & Welsh, 2014, 2015). All other aspects of the experiment remained identical to Experiment 1.

Methods

Participants. Twenty participants (15 women, 5 men) aged eighteen to thirty years (mean age = 23.5 years) were recruited from the University of Toronto community. All participants were right handed and had normal or corrected to normal vision. Participants provided full and informed consent and were monetarily compensated for their time. All procedures were approved and were consistent with the standards put forth by the University of Toronto Research Ethics Board. Prior to analysis, four participants were removed due to technical difficulties that resulted in improper recording of the data.

Apparatus. The apparatus and experimental set up were identical to that of Experiment 1. All display and movement recording properties were consistent across the two experiments.

Task and procedure. The task, timing of the stimuli, and procedure were identical to Experiment 1 except that the gaze of the model in central fixation would shift back to the center

neutral position 150 ms after it shifted to the periphery (see Figure 2 for a schematic depiction of the time-course of an individual trial).

Data reduction and analysis. The data were processed and analyzed in a similar manner to Experiment 1. Sixty-two (62) trials across all participants (1% of all data) were removed prior to analysis for obvious recording and/or experimental errors. As in Experiment 1, trials in which a participant's RT was less than 100 ms or greater than 1000 ms as well as trials in which MT was greater than 1000ms were removed from the analysis (0.2% of all data). Following this initial screening, trials in which RT fell outside of 2.5 standard deviations for each condition within a participant's responses were removed from the analysis (2.3% of all data). All together, 3.5% of the data set was excluded from statistical analysis. One participant's mean MTs were longer than 2.5 SDs of the mean MT for the group as a whole. For this reason, this participant was removed for moving too slowly and not following instructions. Thus, the final sample size was 15 for Experiment 2. Statistical analyses followed those outlined in Experiment 1.

Results

Reaction time. Significant main effects for Target, $F(1,14) = 9.50$, $p < .01$, $\eta_p^2 = .40$, and SOA, $F(4.85, 67.99) = 21.78$, $p < .001$, $\eta_p^2 = .61$ were found. The main effect of Target revealed that RTs to cued targets ($M = 264$ ms, $SD = 33.44$) were shorter than those to uncued targets ($M = 271$ ms, $SD = 30.69$). For the main effect of SOA, there was a significant linear trend, $F(1,14) = 35.29$, $p < .001$, $\eta_p^2 = .72$, revealing that RTs generally increased as a function of SOA. There was also a significant Target by SOA interaction, $F(6, 84) = 3.18$, $p < .01$, $\eta_p^2 = .19$ (Figure 4, center left). Planned comparisons revealed that RTs in reaches to cued targets were significantly shorter than in reaches to uncued targets at the 250 ms, $t(14) = 5.0$, $p < .001$, 95% CI [-26.07, -7.20], $d_z = 1.29$, 400 ms, $t(14) = 2.47$, $p < .05$, 95% CI [-15.01, -1.07], $d_z = 0.64$, 700 ms, t(14) =

2.13, $p < .05$, 95% CI [-17.47, -0.68], $d_z = 0.59$, and 1000 ms SOAs, $t(14) = 2.74$, $p < .05$, 95% CI [-12.18, -1.9], $d_z = 0.71$. There were no other statistically significant differences ($p > .05$) between cued and uncued targets at the remaining SOAs (i.e., 100 ms, 1700 ms, and 2400 ms). Therefore, it appears that there were facilitation effects of cue at shorter SOAs (with the exception of the 100 ms SOA) that dissipated at SOAs longer than 1000 ms. No evidence of IOR was observed.

Movement time. No effect of Target was detected, $F(1,14) = 0.84$, $p = .38$, $\eta_p^2 = .06$, or SOA, $F(6,84) = 1.35$, $p = .09$, $\eta_p^2 = .09$. There was also no significant interaction between Target and SOA, $F(6,84) = .35$, $p = .91$, $\eta_p^2 = .02$. Therefore, neither the cue nor SOA had a significant effect on MT in this experiment.

Initial movement angle. No significant main effect of Target, $F(1,14) = .46$, $p = .51$, $\eta_p^2 = .03$, or Target by SOA interaction, $F(6,84) = .30$, $p = .94$, $\eta_p^2 = .02$, was found. There was, however, a significant main effect of SOA, $F(6,84) = 2.64$, $p < .05$, $\eta_p^2 = .16$ (Figure 4, center right). Accordingly, there was a significant linear trend for SOA, $F(1,14) = 13.32$, $p < .01$, $\eta_p^2 = .49$, revealing that IMAs generally increased as SOA increased. Overall, and consistent with Experiment 1, there was no difference in IMA between reaches to cued and uncued targets.

Discussion

Experiment 2 differed from Experiment 1 in that the gaze cue did not remain fixed on a given target. Following 150ms, the direction of the gaze cue returned from one of the placeholders to the center neutral position and was oriented towards the participant. A different pattern of RTs emerged in Experiment 2 from that in Experiment 1. Of particular interest is the significant Target by SOA interaction for RT. Planned comparisons demonstrated that this interaction was driven by a facilitation associated with the cue at SOAs 250-1000 ms that

diminished at longer SOAs (i.e., 1700 ms). This interaction more closely matches the results of previous experiments, demonstrating a loss of facilitation effects at longer SOAs (Friesen & Kingstone, 1998; Friesen, Ristic, & Kingstone, 2004; Frischen, Bayliss, et al., 2007; Frischen & Tipper, 2004). Despite the diminished cuing effect, however, IOR still did not emerge. This finding is likely due to the persistence of the gaze cue as previous findings only demonstrated IOR when the gaze cue was completely masked (i.e., removed) before the presentation of the target onset (Frischen & Tipper, 2004).

The more theoretically relevant finding from Experiments 1 and 2, however, is that there were no IMA effects despite the RT findings noted here. Although the change in methodology between Experiments 1 and 2 caused a shift in the pattern of RT effects across SOAs, no such change was found for movement trajectories. This repeated null finding in IMA provides some support for the notion that the results of Experiment 1 was not likely to be a Type II error. Thus, collectively, these findings suggest that gaze cueing may not alter activity in the motor system and exert an influence on reaching movements in the way that peripheral cues have been shown to do (e.g., Neyedli & Welsh, 2012).

Experiment 3

Although gaze cues may cause an orienting of attention (as evidenced by the RT effects in Experiments 1 and 2), it appears that these gaze cues may not be sufficiently or strongly linked to representations of pointing or reaching movements in a meaningful way. The disconnect between RT and trajectory effects is in contrast to the previous work showing cuing effects using peripheral cues (e.g., Welsh, 2011; Welsh et al., 2004; 2013). This difference between peripheral cues and social gaze cues may be an informative difference, especially considering eye-hand

coupling, and how eye gaze tends to proceed the hand to the object with which the individual will interact (see Flanagan & Johansson, 2003).

Experiment 3 was conducted to investigate whether or not a social cue that might be more tightly linked to the manual motor system (e.g., a pointing finger) affects the spatio-temporal characteristics of goal-directed movements. Although finger pointing may be social and communicative in a manner similar to eye gaze, the observation of a pointing finger may engage the neural action codes associated with pointing in the observer – e.g., the action observation (putative mirror neuron system; see Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Craighero, 2004). This alternate social cue may then be more closely linked to the reaching or pointing movements employed in the present tasks, leading to a stronger propensity to generate competing response codes that would lead to larger deviations in the trajectory of the participants' hand movements. Indeed, trajectory deviations in reaching movements executed in a Simon effect task have previously been reported when a hand with a pointed finger was used as the stimuli (Welsh, Pacione, Neyedli, Ray, & Ou, 2015). If all social cues affect response initiation processes, but not response planning and execution, then the same pattern of cuing effects in RTs but not IMA that was observed in Experiments 1 and 2 will be observed in Experiment 3. If, on the other hand, a finger pointing towards a target is more closely coupled with the reaching movement being performed, then perhaps RT effects and trajectory deviations will be observed in Experiment 3. It was predicted, therefore, that trajectory deviations would differ more between cued and uncued targets in this experiment.

Methods

Participants. Twenty participants (11 women, 8 men, the age and gender data for one participant are not reported) aged eighteen to thirty three years (mean age = 22.6 years) were

recruited from the University of Toronto community. All participants were right handed and had normal or corrected to normal vision. Participants provided full and informed consent and were financially compensated for their time. All procedures were approved by and were consistent with the standards put forth by the University of Toronto Research Ethics Board. The data set from one participant was removed prior to analysis due to a technical difficulty that resulted in improper recording of the data.

Apparatus. The apparatus and experimental set up were identical to that of Experiments 1 and 2. Recording properties were consistent across the three experiments. The display of the home position and target placeholders was identical to those of Experiments 1 and 2. The centrally presented images consisted of the hand of a Caucasian individual pointing at the participant or at one of the two target locations. The central pointing image measured approximately 7 cm (w) by 6.5 cm (h) and were centred between the two target placeholders.

Task and procedure. The trial procedures for Experiment 3 were identical to those of Experiment 1, except for the stimulus that was used. The left and right pointing finger images measured approximately 12 cm (w) by 6.5 cm (h). As in Experiment 1, the pointed finger cue remained fixed towards the given target placeholder throughout the trial (see Figure 3 for a schematic depiction of the time-course of a given trial). After a variable SOA, one of the target placeholders became solid, signalling the participant to place their index finger in the given target placeholder. The same seven SOAs were used: 100, 250, 400, 700, 1000, 1700, and 2400 ms. Fifteen cued and uncued trials were performed for both the left and right target placeholder at each of the seven SOAs (total trials = 420).

Data reduction and analysis. Two-hundred and twenty-five trials across all participants (2.8% of all data) were removed prior to analysis for obvious recording and/or experimental

error. The start and the end of the movement were determined in the same manner as in the previous experiments. As in the previous experiments, trials in which a participant's RT was less than 100 ms or greater than 1000 ms as well as trials in which MT was greater than 1000ms were removed from the analysis (0.14% of all trials). Following this initial screening, trials in which RT fell outside of 2.5 standard deviations for each participant and condition were removed from the analysis (2.32% of all trials). Statistical analysis was the same as outlined in Experiment 1.

Results

Reaction time. There was a significant effect of Target, $F(1,18) = 6.29$, $p < .05$, $\eta_p^2 = .26$, and a significant Target by SOA interaction, $F(6,108) = 10.43$, $p < .001$, $\eta_p^2 = .37$ (Figure 4, bottom left). The main effect of Target revealed that RTs to cued targets ($M = 344$ ms, $SD = 48.91$) were shorter than those to uncued targets ($M = 354$ ms, $SD = 52.95$). There was no significant main effect of SOA, $F(6,108) = 1.83$, $p = .10$, $\eta_p^2 = 0.09$. Planned comparisons revealed that RTs in reaches to cued targets were significantly shorter than in reaches to uncued targets at SOAs of 100 ms, $t(18) = 4.17$, $p < .01$, 95% CI [-41.29, -13.61], $d_z = 0.96$, and 250 ms, $t(18) = 5.04$, $p < .001$, 95% CI [-47.43, -19.42], $d_z = 1.16$. No other statistically significant cued vs uncued target RT differences emerged across the other SOAs ($p > 0.05$).

Movement time. There were no significant effects of Target, $F(1,18) = .023$, $p = .88$, $\eta_p^2 = .001$, or SOA, $F(6,108) = 1.07$, $p = .29$, $\eta_p^2 = .06$, and no significant interaction between the two factors, $F(6,108) = .044$, $p = .85$, $\eta_p^2 = .02$. Therefore, there was no effect of either cue or SOA on MT.

Initial movement angle. Significant main effects of Target, $F(1,18) = 5.37$, $p < .05$, $\eta_p^2 = .23$, and SOA, $F(6,108) = 2.91$, $p < .05$, $\eta_p^2 = .14$, were found. There was, however, no Target by SOA interaction, $F(4.46,80.36) = .47$, $p = .79$, $\eta_p^2 = .03$ (Figure 4, bottom right). The main effect

of Target indicated that IMAs in reaches to uncued targets were smaller (i.e., more central, M = 26.22, SD = 5.18) than IMAs in reaches to cued targets overall (M = 27.02, SD = 5.69). That is, the movements to locations that were not cued (not pointed at) deviated towards the cued (pointed at) location.

Between experiment analysis. To assess any potential significant differences in trajectory deviations to cued and uncued targets between gaze and pointing cues, the IMA data from the two experiments with the most similar designs were analyzed using a 2 (Target: Cued, Uncued) by 6 (SOA: 100, 250, 400, 700, 1000, 1700, 2400) by 2 (Experiment: 1, 3) mixed ANOVA with Experiment as a between group factor and SOA and Target as within-subjects factors. There was no significant main effect of SOA, $F(6,222) = 1.29$, $p = .26$, $\eta_p^2 = .03$, and no significant interactions between Target and SOA, $F(6,222) = 0.20$, $p = .98$, $\eta_p^2 = .005$, or Target, SOA, and Experiment, $F(6,222) = 1.56$, $p = .16$, $\eta_p^2 = .04$. There was however, a significant SOA by Experiment interaction, $F(6,222)$, $p < .001$, $\eta_p^2 = .10$, suggesting that the pattern of IMAs across SOAs varied differently between the two experiments. The main effect of Target approached but did not reach conventional levels of statistical significance, $F(1,37) = 3.67$, $p = .06$, $\eta_p^2 = .09$. Likewise, the critical interaction between Target by Experiment interaction approached, but did not surpass, conventional levels of statistical significance, $F = 3.79$, $p = .06$, $\eta_p^2 = .09$.

Discussion

Experiment 3 explored the mechanisms of social cueing activated when a cue that more closely matched the response was presented. The finger-pointing cue used in this experiment generated a short-lived facilitatory cuing effect in RTs. Unlike in Experiments 1 and 2, however, significant effects of cue were now also detected in the initial angle of the movement trajectory.

The between experiment analysis suggested that the difference in IMA between cued and uncued targets tended to be larger in Experiment 3 than in Experiment 1, though this difference was not statistically significant. Overall, the results of Experiment 3 suggest that when the social cue (i.e., pointing, in this case) presented more closely matched the response being generated, reach trajectories were more likely to be affected.

General Discussion

The aim of the three present experiments was to investigate the mechanisms of social cueing by assessing the time course of facilitation and potential inhibition in social gaze and finger cueing using an upper-limb reaching task. These experiments were grounded in action-centred theories of attention (Song & Nakayama, 2009; Tipper et al., 1992; Welsh & Weeks, 2010) and previous work showing that the trajectories of limb movements to targets are affected by the attentional mechanisms activated by a preceding cue (Lee, 1999; Welsh, 2011; Welsh et al., 2013). As such, the temporal and kinematic characteristics of upper-limb reaching movements were analyzed to determine the linked attentional and motoric components of facilitation and inhibition in each of the cuing paradigms. Although the analyses of the RTs in each of the experiments were consistent with previous findings related to gaze cuing and generally revealed facilitatory effects of the social cues, the critical findings were that no differences in initial movement trajectory were found between reaches to cued and uncued targets following gaze cues (Experiments 1 and 2). Conversely, there was a significant effect of the cue on the reach trajectories of participants when a pointed finger was used as the cue (Experiment 3). Consequently, the data seem to indicate that task specificity and perception-action coupling (i.e., a direct match in effector, in this case) may play a role in the processing of these cues and, as a result, their subsequent effects on action initiation and execution.

To address the main purpose of the experiments, the present data are consistent with the idea that the mechanisms underlying gaze cues are different from those that lead to stimulus-driven attentional shifts following peripheral cues. This conclusion is based on a comparison between the results of Experiments 1 and 2 and a series of previous studies in which participants complete aiming movements to targets following dynamic peripheral cues (e.g., Lee, 1999; Neyedli & Welsh, 2012; Welsh, 2011; Welsh et al., 2013). In Experiments 1 and 2, clear facilitatory effects associated with the social gaze cue were observed in response initiation times (RTs), but there was no evidence of any manifestation of facilitation (or inhibition) in the movement trajectories. This pair of findings stands in contrast to the results of numerous studies that have provided evidence of excitatory and inhibitory mechanisms expressed in *both* RT and movement trajectories in studies employing peripheral cues to evoke stimulus-driven captures of attention (e.g., Welsh, 2011; Welsh et al., 2013). It has been previously suggested that, because of the tight coupling of attention and action processes, the dedication of attention to a specific location or object activates processes to produce a response to interact with that location (Tipper et al., 1992; Welsh & Weeks, 2010). Thus, the absence of such a tight coupling between attention and action production following gaze cues suggests that the shifts of attention following gaze cues and dynamic peripheral cues are likely to be generated by different mechanisms. Similar conclusions regarding the potential for independent processing channels for social (gaze) and non-social (motion) cues have been previously made (Böckler et al., 2014, 2015).

Conclusions regarding the (dis)similarity of the mechanisms underlying gaze and central symbolic cues are more difficult to draw because there is no study that we are aware of that has directly examined the pattern of RTs and trajectory deviations that emerge following non-predictive centrally-presented symbolic cues such as arrows. Nonetheless, there is evidence from

studies involving keypress tasks that social gaze cues are processed differently from centrally-presented arrow cues (Marotta, Lupiáñez, Martella, & Casagrande, 2012; Marotta, Román-Caballero, & Lupiáñez, 2018). Further, there is a contrast between the results of Experiments 1 and 2 in which no trajectory deviations were observed following gaze cues, and Experiment 3 in which a centrally-presented pointing finger generated facilitatory effects in RT and trajectory deviations. In this sense, not all social cues influence the attention and action system in the same way. As such, social cues (and indeed, non-social centrally-presented cues) should not be taken as one and the same and nuanced explorations of cueing effects are required (see Atkinson, Simpson, & Cole, 2018 for a review and discussion).

As already suggested, the trajectory deviations in the pointing cue task may have emerged because of a match between the cue and the effector that the participant used for the task. Previous work has demonstrated that the relationship between the characteristics of the target and non-target stimuli and the type of response that will be executed can have an influence on the interference caused by distractors. For instance, Welsh and Pratt (2008; see also Welsh & Zbinden, 2009) demonstrated that offset distractors caused interference in responding to an onset target in a key press task, but not in an upper-limb aiming task. The authors suggested that this response-related difference in the impact of the offset distractor on an onset target was due to the differences in action affordances of the stimuli between the two tasks. Because the visuomotor system needs a stable source of information about the target to ensure that accurate termination of an aiming movement, an offset stimulus is not salient to the attention/action system because it does not provide that stable source of visual information (there is no longer any stimulus information at the location of an offset). Hence, the offset distractor does not capture attention and cause interference when an aiming movement is executed because it is not salient to the

system when an aiming movement is required. In contrast, the attention/action system does not need a stable source of endpoint information to ensure accuracy when discrete button responses are being executed. Hence, any dynamic change in the environment is salient to the visuomotor system and, in this case, offset stimuli can capture attention and cause interference. Similarly, Bekkering and Neggers (2002) found that visual processing of distractor items were different when participants prepared a reach-to-grasp action as compared to a reach-to-point action. Specifically, participants made more saccadic eye movements to a non-target object with the wrong orientation when they reached-to-grasp the target object than when they reached-to-point to the object. When the distractor item was of a different colour, there were no differences between the tasks. Thus, orientation was a salient feature that caused enhanced distraction when performing grasping actions, in which orientation is a key feature. Overall, these studies demonstrate that there is an interaction between response type (i.e., action) and the stimulus characteristics that capture attention.

In the context of the present work, it is possible that the nature of the relationship between the characteristics of the upcoming action and those of the stimuli shape processing of the cue stimuli in the current study and influenced the motoric effects of spatial attention. Specifically, it is likely that neural codes for visual perception of the gaze cue and hand cue are coupled with different neural codes for action. There is a great deal of overlap between the neuronal networks active in action observation and those active during action execution (Grèzes & Decety, 2001). This overlap may be rooted in a mirror neuron-like system (MNS) wherein neurons are active for both action perception and execution (Rizzolatti & Craighero, 2004). Consequently, when an action is observed, (e.g., the shift of gaze or the turning of a hand) the perception of this action can in turn activate the neural codes associated with actual performance and control of that

action. Perhaps because of the greater overlap in the coding of hand cues and hand actions, the pointed finger led to the activation of a compatible response whereas the eye gaze cue did not.

Further, it should be noted that neurophysiological work has demonstrated that eyes (faces) and hands (bodies) are represented and processed in distinct areas of the human cerebral cortex. For instance, areas of the visual cortex have been found to be particularly selective to the perception of faces (e.g., occipital face area [OFA], and fusiform face are [FFA]) while other distinct areas are selective for the perception of bodies, and hands in particular (e.g., the extrastriate body area [EBA], and the fusiform body area [FBA]) (Peelen & Downing, 2007). Additionally, in parietal cortex, the lateral intraparietal area (LIP) is connected with other areas associated with gaze control (e.g., the frontal eye field, and the superior colliculus) whereas the medial intraparietal area (MIP) is more active in reaching movements and is connected with frontal regions that are also associated with reaching (Cisek & Kalaska, 2010). Therefore, it is possible that the different apparent motion cues (i.e., eye gaze shift and hand rotation) used in this experiment were perceived with distinct areas and were then linked with distinct actions and, consequently, control systems.

In summary, the current experiments demonstrated that while gaze shifts may facilitate temporal aspects of the initiation of reaching movements such as RT, there is little effect of gaze cueing on the spatial parameters of reaching movements. These data indicate that it is unlikely that a response producing process is activated when a shift of attention has been made to a location following a gaze cue. When the gaze cue was replaced with a finger-pointing cue, however, spatial effects on the movement trajectory were seen, indicating that a response producing process *was* activated following the finger-pointing cue. Overall, this work highlights the important interactions between action systems, cognition, and attention by demonstrating

how the effector of a social cue (i.e. eye or hand) can influence the spatial characteristics of a reaching response.

Footnote

1. Although the entire movement trajectory was recorded, we chose to analyze movement angle at only one point - 20% of MT (for discussions of techniques that may be used to analyze the whole trajectory, see Gallivan & Chapman, 2014; Lins & Schöner, this issue). This time point of 20% of movement time (which falls approximately at peak acceleration) was chosen because we believe this point (and similar points early in the trajectory) provides an accurate characterization of the movement planning activated by the stimuli at movement initiation. Because the movements in the present study were executed in full vision, time points later in the trajectories may be contaminated by any online correction processes as the movements converge on the target endpoint as the movement unfolds. Hence, the chosen time-point is likely to best represent the simultaneous activation of competing response codes without contamination from online corrections to movement. Although we report only the analysis of this one point, we conducted a subsequent analysis of additional time points (40%, 60%, and 80% of MT) for each experiment. The results of the ANOVAs when all of these time points were included were consistent with the analysis of IMA at only 20% of movement time that is reported in the current paper.

Acknowledgments

This research was supported by grants and scholarships from the Natural Sciences and Engineering Research Council of Canada. The authors thank Joëlle Hajj and Saba Taravati for their help with data collection.

Open Practices Statement

None of the data or materials for the experiments reported here is openly available, and none of the experiments was preregistered.

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Figures

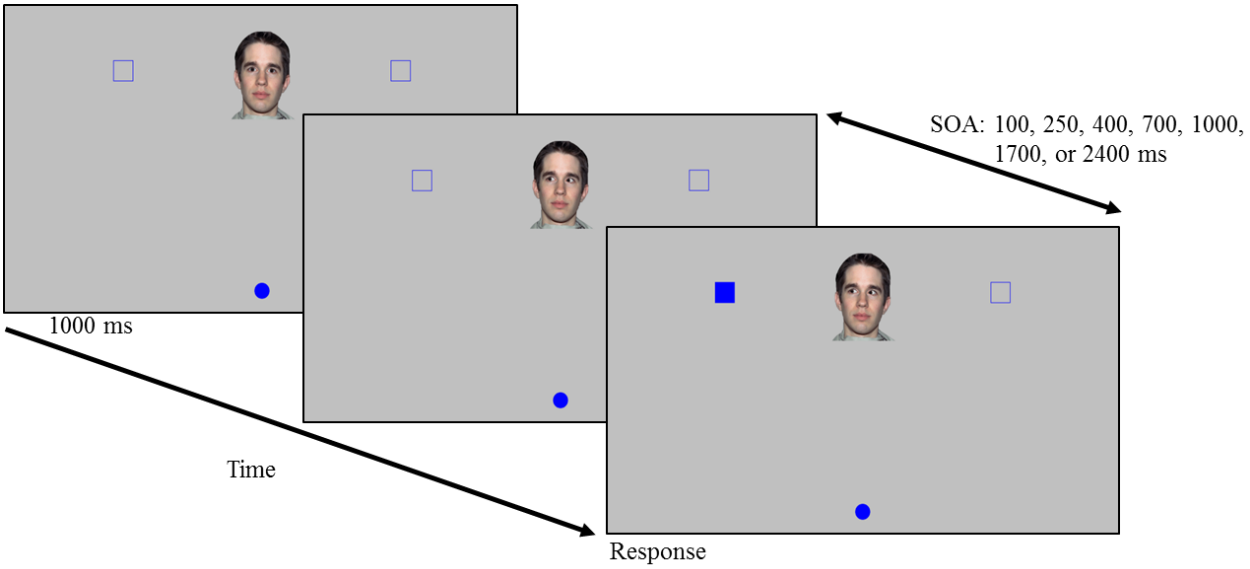

Figure 1. Schematic of the timeline for a given trial. The gaze cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

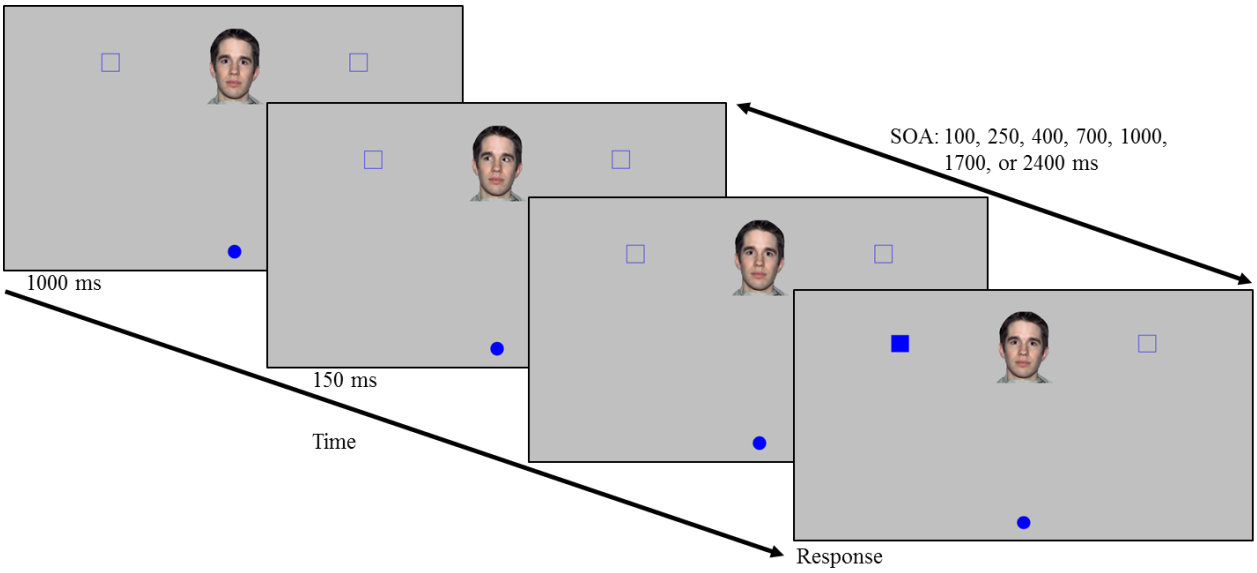

Figure 2. Schematic of the timeline for a given trial. The gaze cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

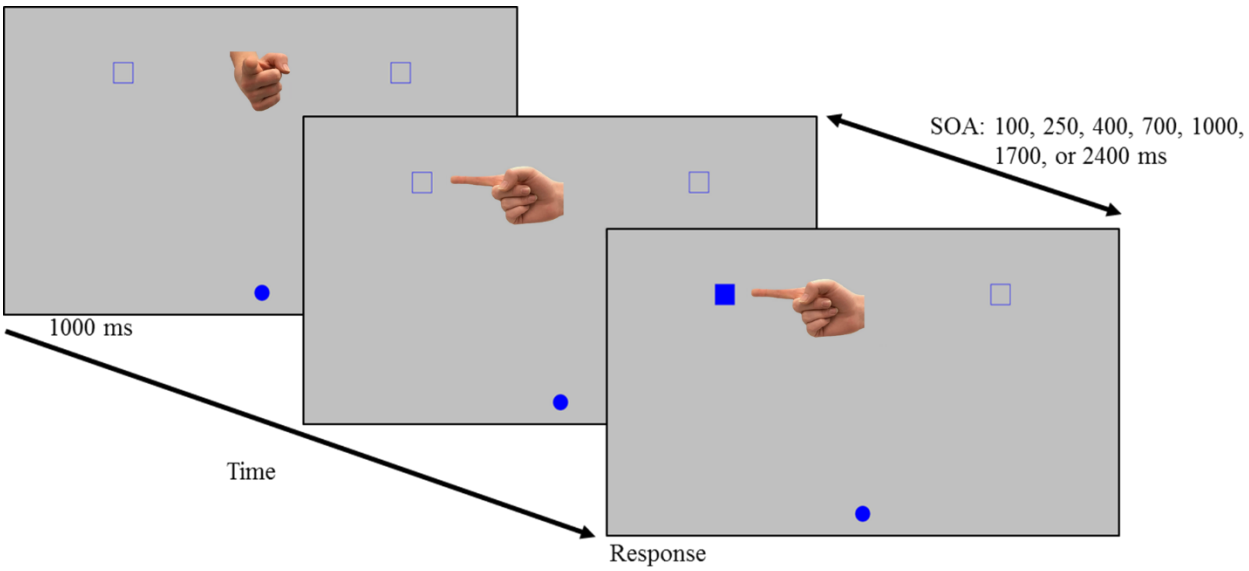

Figure 3. Schematic of the timeline for a given trial. The pointing cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

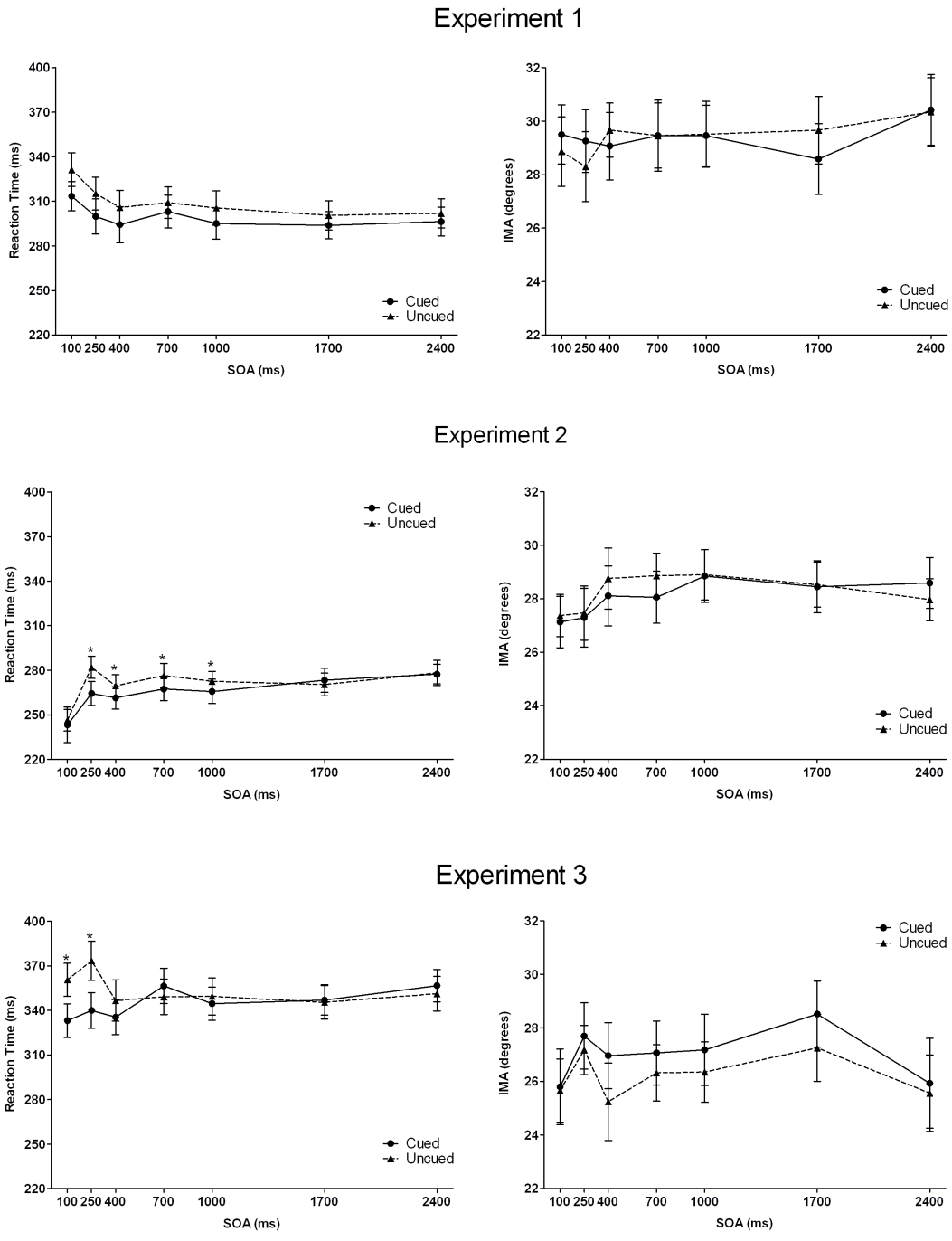

Figure 4. Reaction Time (left side panel) and initial movement angle (IMA, right side panel) for reach of Experiments 1, 2, and 3. Asterisks (*) denote significant differences between cued and uncued trials.